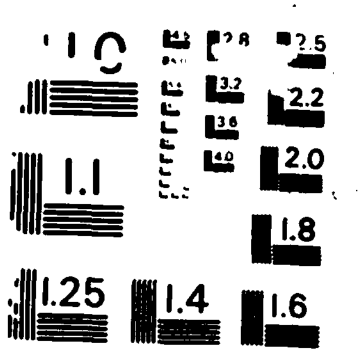
AD-A193 873 TRANSFORMATIONS OF SHORT-TERM VISUAL MEMORY(U) 1/1
PENNSYLVANIA UNIV PHILADELPHIA S STERNBERG 15 MAR 88
N00014-85-K-0643

UNCLASSIFIED F/G 5/8 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A193 873

SECURITY CLASSIFICATION OF THIS PAGE

DTIC FILE COPY

(4)

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; Distribution unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: University of Pennsylvania; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Personnel and Training research program, Office of Naval Research (Code 1142 PT)
6c. ADDRESS (City, State, and ZIP Code): 3815 Walnut Street, Philadelphia, Pa. 19104-6196	7b. ADDRESS (City, State, and ZIP Code): 800 North Quincy St., Arlington, Va. 22217-5000
8a. NAME OF FUNDING / SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N00014-85-K-0643
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO 61153N; PROJECT NO RR04204; TASK NO RR04206-01; WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification): Transformations of short-term visual memory: Final report

12. PERSONAL AUTHOR(S): Sternberg, Saul

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final Report	FROM 85/9/01 TO 87/8/31	1988 March 15	15

16. SUPPLEMENTARY NOTATION: Work collaborative with AT&T Bell Laboratories

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Psychology, information-processing, visual, memory, reaction-time
05	10		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This is the Final Report of research supported by a contract entitled "Transformations of Short-Term Visual Memory." After a section on Short-term dynamics of visual representation: Background and previous research, the report provides a synopsis of the principal research supported by the contract, under the following headings: Technical advances, Principal phenomena in the spatial probe paradigm, Comparison of visual and tactile probes, The roles of uncertainty about position, target, and response in information retrieval, The effect of memory load on the time to name an element indicated by a spatial probe, Nature of the transformation process, Comparison of the time course of slope and intercept changes with probe delay, Test of direct access by color, Comparison of naming of a marked element with location-specific matching, Location-specific matching of digits versus unfamiliar and nameless shapes, Relation of the rapid transformation of small arrays to the decay of iconic memory of large arrays, and Plans for use of event-related potentials (ERPs) to monitor the rapid transformation.

DTIC ELECTE APR 0 4 1988 S E

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL: Dr. Harold Hawkins	22b. TELEPHONE (Include Area Code): 202-696-4323; 22c. OFFICE SYMBOL: ONR1142PT

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Office of Naval Research
Contract N00014-85-K-0643 (University of Pennsylvania)
Final Technical Report
Title: **Transformations of Short-Term Visual Memory**
Principal Investigator: Saul Sternberg
Collaborators: R. L. Knoll & D. L. Turock, AT&T Bell Laboratories
Reporting Period: From 85-09-01 to 87-08-31

1. INTRODUCTION

In domains ranging from neurophysiology to computational modeling, recent work on visual-information processing indicates that even a single act of seeing entails the coding and recoding of the visual stimulus through multiple levels of representation (e.g., Marr, 1982; Schiller, 1986). Within cognitive psychology, the attempt to characterize these levels of representation has focused primarily on variants of the following task: an array of letters or digits is briefly presented and the subject attempts to identify and remember the characters it contains. Even in this highly constrained and long-studied task, there remains uncertainty and controversy about how many different representations exist, what their properties are, how long each can be maintained, and how the transformation from one to another is accomplished (e.g., see Coltheart, 1984). The present research had two broad aims: First, to better understand visual representation within the conventional cognitive approach, by focusing on the *computational* characteristics of the internal representations of character arrays, rather than on their *informational* content as most previous studies have done. Second, to begin to extend this approach to the processing of visual stimuli other than alphanumeric characters.

2. SHORT-TERM DYNAMICS OF VISUAL REPRESENTATION: BACKGROUND AND PREVIOUS RESEARCH

Simon (1978) has distinguished two ways of characterizing mental representations, in terms of their *informational* content, and in terms of their *computational* properties. In Simon's terms, the traditional cognitive approach to early visual processing is concerned primarily with *informational* aspects of the representation, assessing the amount of information it contains as a function of its 'age' (in msec), with *accuracy* of retrieval as the principal measure. Examples include the classic studies that gave rise to the concept of iconic memory (Averbach & Coriell, 1961; Sperling, 1960) and that revealed a progressive loss of information from large arrays. In contrast to this approach, my colleagues and I have developed a new set of experimental paradigms that allow us to focus on the *computational* characteristics of visual information processing: *How* information in the visual system is represented, maintained, transformed, and extracted during the processing of arrays. In these paradigms the arrays viewed by subjects are sufficiently small such that performance is relatively accurate even after a long delay. The subject's internal representation of a brief display is probed in different ways, with instructions to respond as rapidly as possible while maintaining accuracy; the principal measure in this approach is *latency* of retrieval.[1] Conditions associated with high accuracy characterize many real-world situations and are likely to call upon mechanisms different from those used in the

1. Despite their usefulness in the study of informational aspects of visual representation, accuracy measures may be inferior to latency measures as a basis for inference about computational aspects. Pashler (1984, p. 432), e.g., has made this argument in his review of attempts to decide between "early selection" and "late selection" theories of attention in the processing of visual arrays.

Sponsored in part by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No.N00014-85-K-0643, Contract Authority Identification Number NR 154-533/5-17-85.

traditional overload conditions. Whereas the central issue in the traditional approach to early visual processing has been the *passive persistence* of a visual image after display termination, our work with displays that do not exceed the system's capacity has revealed processes of *active transformation* or *encoding* of stimulus representations, which alter the mechanisms by which information is extracted. Briefly, the paradigms we have used include:

(a) *Spatial Probe Paradigm.* The probe, usually a visual marker, specifies location; the response is to name the element that is or was in that location.
(b) *Identity Probe Paradigm.* The probe is usually the spoken name of a target element; the response is to name the element in the array to the right of the target.
(c) *Probed Reciting Paradigm.* The probe, a tone burst, specifies direction; the response is to recite the entire array in that direction.
(d) *Location-Specific Matching Paradigm.* The probe is a test element that also marks a target location; the response is "yes" or "no", depending on whether target and test elements match.

When the present contract began we had collected only preliminary data in paradigm (d); Our work during the contract period concentrated almost entirely on paradigms (a) and (d).

Other critical ingredients of the methods we had developed at the start of the contract period are investigation of performance at various probe delays up to about 2 seconds, variation in the number of displayed characters or other elements (array size), and statistical control of retinal eccentricity. Variation of array size, s, is crucial for two principal reasons: First, the effect of probe delay on reaction time (RT) interacts strongly with array size, sometimes actually differing in direction for array sizes within a small range. Second, characteristics of the functions $\{RT(s,d)\}$ that relate mean RT to array size at different probe delays, d, lead to a decomposition of the effects of delay that permits powerful inferences — inferences that could not be supported by the study of performance with a single array size.[2] During the period covered by the present report we developed multiple-regression techniques to aid in data description, and robust fitting procedures to deal with the high tails of reaction-time (RT) distributions; we also integrated an infra-red limbus eye-tracker into our experimental procedure to better control eye position. We have used the $RT(s)$ function and changes in $RT(s)$ with probe delay to infer properties of the internal representation and of the transformations it undergoes. In our work thus far $RT(s)$ changes rapidly with delay; moreover, in three of the paradigms it is either flat or strikingly linear at all delays, and hence can be fully characterized by its changing slope and intercept.

What do our findings imply for the nature of early visual representations and the processes that generate and transform them? We have discovered, for example, that the earliest representation is distinguished by a property of *direct access by spatial position* (search of elements in other positions is not necessary to retrieve an element whose position is specified), and also by *directional symmetry* (the initial representation of a row of characters can be scanned in either direction). Given plausible retrieval operators, these properties are consistent with an array-format representation (cf. Marr, 1982). As the representation is transformed, both of these properties rapidly disappear: The patterns of retrieval times to date provide converging evidence for a dramatic transformation of the internal representation of a character array that is

2. Another line of research (initiated by Posner et al.) in which latency methods have been used to study the nature of visual representation as a function of storage time, has been limited principally to single characters — i.e., arrays of size one. See, e.g., Posner & Keele, 1967.

complete in about 0.7 seconds. The linearity of the *RT(s)* functions described above may indicate that insofar as there is any effect of array size in those paradigms, it reflects a process of serial search, whose mean rate changes systematically as the representation is transformed.

3. SYNOPSIS OF THE PRINCIPAL RESEARCH SUPPORTED BY THE CONTRACT

NOTE: Reports containing additional details are referenced by numbers in square brackets, and listed in the final section of references.

3.1 Technical Advances [3,6]

Our substantive findings were made possible by some of the following technical advances.
(1) To help overcome unavoidable nonorthogonalities in experimental design we devised a multiple-regression method to provide descriptions of our data; to deal with the variability induced by the high tails of RT distributions we fitted our multiple-regression models by a robust method. Because robust regression has seldom been used in such applications, we performed a careful assessment, comparing it to ordinary least squares with respect to several criteria that we developed.
(2) The linear function *RT(s)* that relates mean RT to array size can be described by slope and intercept parameters. We developed new rationales for the choice of intercept.
(3) We found a way to compare the time courses of the changes with probe delay in slope and intercept parameters from the same paradigm, and also the slopes of corresponding functions from different paradigms.
(4) Three of four *parallel transformation* models that we developed lead us to expect that RTs at intermediate probe delays are a probabilistic mixture of the RTs at short and long delays. We found a way to test this implication by using properties of the RT variance.
(5) We developed computer simulation tools for testing *serial transformation* models.
(6) We incorporated an infra-red limbus eye-tracker into our experiment-running program to measure and control eye position, arranged such that a trial is interrupted and feedback given if the eyes move more than an allowed amount. We ran one full experiment successfully with this augmentation, using the location-specific matching paradigm.

3.2 Principal Phenomena in the Spatial Probe Paradigm [2,3]

At all probe delays the effect of array size on mean RT to name the element in the marked location, described by the *RT(s)* function, is approximately linear for $2 \leq s < 6$, and can thus be indexed by the slope of that function. When the probe appears early (50 msec before array onset) the slope is virtually zero (Fact 1). As the probe is delayed, the slope grows and the intercept shrinks (Fact 2), with asymptote reached at a probe delay of about 0.7 sec.

3.3 Comparison of Visual and Tactile Probes [2,5]

Our initial work during the contract period was completion and analysis of a large experiment (about 36,000 observations) in which we examined performance with visual and tactile probes at six probe delays, and which had been conducted to help discriminate among three possible explanations of Fact 1:
(1a) *Direct Access by Spatial Position.*
Early in the life of the memory of a display, no search over other elements is needed to retrieve information about a particular element when that element is specified by its spatial position.
(1b) *Marker-Induced Distinctiveness.*
When the displays of visual marker and array are in sufficiently close temporal proximity, an

internal representation is formed of their superimposed images. The marked digit then has the marker integrated with it, making it a highly distinctive pattern. Search for such a distinctive pattern among plain digits is very rapid, so the effect of display size is negligible.

(1c) *Marker-Induced Shift of Visual Attention.*

The visual marker's abrupt onset automatically causes visual attention to shift to its locus. If an array element is displayed at that locus during the period in which attention is concentrated there, then the element in that locus is the first one examined in any search. If we assume that the search for a location under these conditions is self-terminating, then the search ends where it began, so the size of the array has no effect.

Explanations (1b) and (1c) depend on the probe being visual, hence the comparison of tactile with visual probes to test them. Performances with the two kinds of probe were remarkably similar: Facts 1 and 2 hold for both, and parameters are virtually identical. Tactile markers convey information, but they are unlikely to add visual distinctiveness to a digit, or to automatically cause a shift of visual attention. For Fact 1, this leaves Explanation (1a) — the direct-access property.

Similarity of performance with visual and tactile markers also allows us to reject a potential explanation of Fact 2:

(2a) *Change from Retinotopic to Spatiotopic Coordinates.*

It has been proposed that the internal representation of visual information changes over time from an initial form, referred to retinal coordinates, to a later form, referred to extra-retinal coordinates. (See, e.g., Breitmeyer, Kropfl, & Julesz, 1982.) If so, it seems reasonable that initially (when we find direct access) less "computation" would be required to determine the spatial relationship between the constituents of visual displays, even if nonsimultaneous: Their locations can presumably be "directly" compared. Later (when we find that search is necessary) both must be referred to an extra-retinal coordinate system. Because the mapping from tactile marker to visual array would have to be "indirect" at all delays, the similarity of our findings for tactile and visual markers argues against this explanation of Fact 1.

3.4 The Roles of Uncertainty about Position, Target, and Response in Information Retrieval [4]

In a pair of experiments we assessed the roles of uncertainty about position, target, and response, and changes in such uncertainty with probe delay, in producing the dramatic effects of storage time on the retrieval of visual information specified by location. While an array resides in memory, information of three different kinds may accumulate that might shorten the RT to the probe and that might especially benefit small arrays, thus inducing an increase in the slope of the $RT(s)$ function (Fact 2). We thus have three additional candidates for explanation of Fact 2:

(2b) *Reduction of Spatial Uncertainty.*

The set of possible probe locations is specified by the set of occupied array locations. Once the array has been presented, this set of locations can be discriminated, causing the spatial uncertainty of the probe to be reduced, with more reduction achieved for smaller arrays. If spatial uncertainty influences the time to discriminate probe location in this situation, the result would be an increase in the slope of the $RT(s)$ function.

(2c) *Reduction of Target-Stimulus Uncertainty.*

(2d) Reduction of Response Uncertainty.

While awaiting a delayed probe, the subject assimilates information about which digits it contains. As this information is assimilated, stimulus and response uncertainty are reduced; the smaller the array, the greater the reduction. If stimulus and/or response uncertainty influences the time to decode the representation of the target element and/or generate the response in this situation, the result would be an increase in the slope of the $RT(s)$ function.

To test alternatives 2b, 2c, and 2d, we constructed two new experimental procedures. In one procedure (*advance location information*) we provided advance information of the set of alternative locations that might be queried by the probe. Insofar as *spatial uncertainty* plays a role in processing of the probe, we expected that this manipulation would especially benefit small arrays, and thus would increase the slope of the *RT(s)* function, supporting explanation (2b). In a second procedure (*advance identity information*) we provided advance information of the set of alternative target stimuli and responses. Insofar as *target-element uncertainty* and *response uncertainty* play roles in generation of the response, we expected that this manipulation would also be especially beneficial for small arrays, and thus would also increase the slope of the *RT(s)* function, supporting explanations (2c) and/or (2d).

In sharp contrast to these expectations, we found no effect of our manipulations on the slope of the *RT(s)* function. This reduces the likelihood that the dramatic increase in slope with probe delay is associated either with operations that precede access to the internal representation of the array (processing of the probe), or with operations that follow such access (generation of the response). By excluding these alternative accounts of the increase in slope with probe delay, we have strengthened the argument for a fourth explanation of Fact 2:
(2e) *Loss of the Direct-Access Property.*
The property of direct access by spatial position is lost, as an initial random-access memory (array-format representation) is transformed into a sequential-access memory.

3.5 The effect of Memory Load on the Time to Name an Element Indicated by a Spatial Probe

If transformed array elements load memory more than untransformed ones, then memory load would increase with probe delay. We ran five experiments to test the extent to which such an increasing memory load contributes to the increasing effect of array size with delay. All except the last experiment had flaws. On the critical trials in this last experiment we presented two arrays successively, the second of size $s=6$, in which each element in the first was also present at the same location in the second. Only a subset of the elements of the second array appeared in the first. Thus we were able to (a) vary the size of the ostensible memory load (determined by the size of the initially-presented subset), at the same time as we were able to (b) use a location probe to designate an element that was present only in the second array, to avoid the possibility that the reaction time was determined by the outcome of a race between two searches, one applied to each array. Results indicate a memory load effect of about 13 msec/element, only a small fraction of the 70 msec/element slope generated by appropriately delayed probes. We conclude that the growth of memory load may play a role in the increasing slope of the *RT(s)* function with probe delay, but it is a minor one; the bulk of the effect appears to be due to a loss of the direct-access property.

3.6 Nature of the Transformation Process [3]

Using data from the spatial-probe paradigm we investigated both serial and parallel models of the transformation process. According to *serial models*, the transformation is applied successively to the elements (digits) in the array until all elements have been transformed. It follows, intuitively, that because larger arrays take more time to transform, mean RT will reach asymptote later for larger arrays, so that if the *RT(s)* function is linear at long probe delays, it will be concave down at intermediate delays. Computer simulations of six specific realizations of the serial model confirmed the intuition: In contrast to our data, the fitted functions at intermediate probe delays were somewhat nonlinear. However, for all model variants except those in which the time to transform an element had zero variance, we were able to account very well for the change with probe delay in slope and intercept parameters of *RT(s)*. One possibility, admittedly implausible, is that artifacts (such as differential speed-accuracy

tradeoffs for different array sizes) might produce slight alterations in the form of the $RT(s)$ function and thus obscure the "true" downward concavity. For this reason, we should seek additional tests of the idea that the transformation process is sequential.

According to simple *parallel models* of the transformation process, the transformation is applied simultaneously to all elements in the array and proceeds at a rate that is independent of array size. For three of the four variants of such models that we considered, the RT distribution at an intermediate delay should be a binary probabilistic mixture of the distributions at longer and shorter delays. We devised a test based on the RT variance that depends on this property, subjected our data to this test, and found that the variance at intermediate delays was too small relative to what was expected from the variances at longer and shorter delays. This test is attractive because it depends on only weak assumptions; it should be applied to data collected in an experiment specifically designed for that purpose.

3.7 Comparison of the Time Course of Slope and Intercept Changes with Probe Delay [3,5]

One of the striking characteristics that we discovered of the way in which the $RT(s)$ function changes as the probe is delayed is that the time course of the changes in its slope and intercept are virtually identical. That is, the proportion of total change that is attained by a given delay is approximately the same for the two parameters. Because these two parameters are likely to reflect different subsets of the processes that occupy the time between probe and response, and because there is no reason to expect the effects of probe delay to have the same time course (in the sense defined above) for these two subsets, the property is surprising, and places strong constraints on the underlying mechanisms. One simple way in which the property could arise is if the $RT(s)$ function at any intermediate delay is a probabilistic mixture of the corresponding functions at two extreme delays, with a mixing probability that changes with delay. That such a mixture could arise from parallel transformation processes, as mentioned above, makes further testing of such processes of special interest.

We also compared the time courses of change of the slopes of two sets of $RT(s)$ functions, one set from the identity-probe paradigm and the other set from the spatial-probe paradigm. Here, also, we found the time courses to be very similar, suggesting that performances under the two paradigms are alternative reflections of the same transformation process.

3.8 Test of Direct Access by Color

One method often used to speed access to information in visual displays is to distinguish elements of such displays by color. Under conditions that were otherwise the same as those we use in the spatial-probe paradigm, we tested whether there was direct access to an element so distinguished. Even when the color to be selected was the same from trial to trial (unlike the marked location in the spatial-probe paradigm) we found that search of other elements is required: we did not find evidence for direct access. It is possible that this result is a consequence of the relative latencies of color and form discrimination when the two attributes are presented simultaneously. We know from the spatial-probe paradigm that the property of direct access is transient, with the slope of the $RT(s)$ function rising rapidly with delay of a location marker. Insofar as color is discriminated with a delay relative to form in our situation, selection by a simultaneous color attribute may be equivalent to selection by means of a delayed marker.

3.9 Comparison of Naming of a Marked Element with Location-Specific Matching [7]

We ran several experiments using the location-specific matching paradigm with arrays of digits. One of our aims was to compare performance here, where naming is not required, with performance in the spatial-probe paradigm where it is. To what extent does our evidence for a

rapid transformation, or even the occurrence of such a transformation, depend on the requirement to name one of the array elements? We found clear evidence for a flat function (indicating direct access) with early probes, and for both a rise in slope and a fall in intercept as the probe was delayed. Overt naming thus appears not to be critical for these phenomena.[3]

A second aim was to investigate selective access as a function of storage duration. To investigate direct access we must measure the extent to which the *presence* of elements in unprobed array locations influences the response to the probe. To investigate selective access, on the other hand, we must measure the extent to which the *content* of unprobed array locations influences that response. The matching procedure permits us to measure selectivity of access by examining the effects of a match of the probe to an element in other than the probed location — that is, the effects of the presence of a mislocated target. Insofar as access is selective, there should be no such effect. That is what we found, for early probes. But just as direct access disappears as the probe is delayed, so does selective access disappear. When it disappears, the mislocated target has an inhibitory effect on negative responses (mismatches); in a more recent experiment in which we used mislocated targets on positive trials (where arrays also have correctly-located targets) we found facilitation.

In another experiment we have been investigating the effects of distance within the array between the mislocated target and the probe, as a function of probe delay, to further explore the nature of the transformation. One possibility, for example, is that the effect of a mislocated target "spreads" to more remote locations as the transformation proceeds. On the other hand, if we are seeing a changing mixing probability of two array representations, we would expect no change with probe delay of the (normalized) gradient of such effects over distance. As the present report is being written, this experiment is in progress.

3.10 Location-Specific Matching of Digits versus Unfamiliar and Nameless Shapes [7]

In a final experiment using the location-specific matching paradigm we used arrays composed of unfamiliar shapes with no learned names. Most studies of short-term visual information processing have used alphanumeric characters; little attention has been paid to the question of generality. One virtue of the location-specific matching procedure is that because it does not require naming we are not restricted to nameable forms. Our initial results suggest that for early probes the direct-access property applies here, also, and, more surprisingly, that there is a similar transformation (albeit with a longer time course) to which arrays of such elements are subject. This finding raises the possibility that the product of the transformation does not represent a string of names, as one might otherwise have thought. Again, more work is needed, possibly with more discriminable array elements to reduce error rate, and also with other changes in method that, we have found, reduce variability.[4]

---

3. Because the response set is independent of array size in this paradigm, our finding here adds to other evidence (Section 3.4) against any important role of differential response uncertainty in the effects of probe delay.

4. One of these changes is the incorporation of an infra-red limbus eye-tracker into the experimental procedure to measure and hence control eye position at critical times during each trial. The variability reduction achieved by this change and others in an experiment with digits as array elements was, however, associated with alteration of neither our principal findings nor their interpretation.

3.11 Relation of the Rapid Transformation of Small Arrays to the Decay of Iconic Memory of Large Arrays

With digits as array elements, the transformation we have been studying seems to be complete in less than a second, and proceeds very rapidly during the first third of a second. This suggests a relation to the rapid decline in storage capacity shown in iconic memory experiments with large arrays and partial report procedures, shown by Averbach & Coriell (1961) and Sperling (1960). One way to study the relationship between the two sets of phenomena would be to use manipulations that are known to influence the duration of iconic storage and examine their effects on performance with our procedures and small arrays. Do conditions that prolong iconic storage of large arrays also increase the time taken by the purported transformation of small arrays? In our first attempt to investigate this question we have been testing a subject we discovered accidentally whose iconic memory is extremely long-lived, as measured by a variant of Sperling's (1960) procedure.[5] We plan next to test him in our spatial-probe paradigm with small arrays.

3.12 Design for Use of Event-Related Potentials (ERPs) to Monitor the Rapid Transformation

Suppose that our inferences from the patterns of RT data in these experiments are correct, and that the retrieval process(es) elicited by probes at different delays are based on different representations of the stored information. Then the gross electrical activity of the brain associated with these retrieval processes may also differ. In particular, if different brain structures underlie the different representations, and the retrieval process that uses a representation is localized in the corresponding brain structure, then the electrical activity associated with retrieval processes at different delays may have different distributions over the cortex. Thus the ERP might initially reflect the "visual" processes subserved by visual mechanisms, and later reflect nonvisual processes subserved by other mechanisms.

Based on this observation, and in collaboration with M. J. Farah of Carnegie-Mellon University, we have planned an exploratory study see whether such a difference in the distribution of activity can be detected in ERPs to probes at different delays. If so, then this would open the way to studying the *time course* of this change in the activity distribution, and to comparing it to the time course of the change in representation inferred from behavioral measures.[6]

4. CONCLUSION

Not only does research of this kind increase our fundamental knowledge of how people process visual information, but it is also likely to have practical implications in display design,[7] for example, and in the understanding of pathologies of visual processing. The basic knowledge acquired in such quantitative behavioral studies of visual information processing also provides crucial guidance for brain research and computational models.

---

5. It may or may not be a coincidence that this subject has juvenile diabetes.

6. T. R. Bashore of the Medical College of Pennsylvania has offered us the use of his ERP laboratory for this study.

7. Examples of findings with practical relevance are the effectiveness of tactile stimuli and the superiority of location markers over color differentiation in guiding visual attention, the opposite effects of storage time on the speed of access to small versus large arrays, and the long-persisting advantages of simultaneous (array) over sequential presentation for flexibility of retrieval.

REFERENCES

Averbach, E., & Coriell, A. S. (1961) Short-term memory in vision. *Bell System Technical Journal, 40,* 309-328.

Breitmeyer, B. G., Kropfl, W., & Julesz, B. (1982) The existence and role of retinotopic and spatiotopic forms of visual persistence. *Acta Psychologica, 52,* 175-196.

Coltheart, M. (1984) Sensory memory. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention & performance X.* Hillsdale, N.J.: Lawrence Erlbaum Associates. Pp. 259-285.

Marr, D. (1982) *Vision.* San Francisco: Freeman.

Pashler, H. (1984) Evidence against late selection: Stimulus quality effects in previewed displays. *Journal of Experimental Psychology: Human Perception and Performance 10* 429-448.

Posner, M. I.. & Keele, S. W. (1967) On the decay of information from a single letter. *Science, 158,* 137-139.

Schiller, P. H. (1986) The central visual system. *Vision Research, 26* 1351-1386.

Simon, H. A. (1978) On the forms of mental representation. In C. W. Savage (Ed.) *Perception and cognition: Issues in the foundations of psychology. Minnesota Studies in the Philosophy of Science, Volume IX.* Minneapolis: University of Minnesota Press. Pp. 3-18.

Sperling, G. (1960) The information available in brief visual presentations. *Psychological Monographs, 74* (11, Whole No. 498).

REPORTS ON THIS LINE OF RESEARCH PRIOR TO THE CONTRACT PERIOD

Sternberg, S. Knoll, R. L. & Leuin, T. C. Existence and transformation of iconic memory revealed by search rates. Bell Laboratories Technical Memorandum, January 1975.

Sternberg, S. & Knoll, R. L. Transformation of visual memory revealed by latency of rapid report. AT&T Bell Laboratories Technical Memorandum, April 1985.

REPORTS OF WORK SUPPORTED BY THE CONTRACT

NOTE: Reports [2], [3], and [6] have been issued as ONR technical reports. Report [4] will be so issued, as will reports [5] and [7] when completed.

[1] Turock, D. L. A new technique for measuring transformations of visual memory. AT&T Bell Laboratories Technical Memorandum, September 1985.

[2] Sternberg, S., Knoll, R. L., & Turock, D. L. Direct access by spatial position in visual memory: 1. Synopsis of principal findings. AT&T Bell Laboratories Technical Memorandum, December 1985. Also paper presented at the Psychonomic Society Meeting, November 1985, with the title "Direct access by spatial position in visual memory."

[3] Sternberg, S., Knoll, R. L., & Turock, D. L. Direct access by spatial position in visual memory: 2. Visual location probes. AT&T Bell Laboratories Technical Memorandum, November 1986.

[4] Sternberg, S., Knoll, R. L., & Turock, D. L. Direct access by spatial position in visual memory: 3. The roles of uncertainty about position, target, and response in information retrieval. AT&T Bell Laboratories Technical Memorandum, July 1987.

[5] Sternberg, S., Knoll, R. L., & Turock, D. L. Direct Access by spatial position in visual memory: 4. The roles of marker-target integration and automatic shifts of visual attention in information retrieval. AT&T Bell Laboratories Technical Memorandum, In preparation, March, 1988.

[6] Sternberg, S., Turock, D. L., & Knoll, R. L. Steps toward an empirical evaluation of robust regression applied to reaction-time data. AT&T Bell Laboratories Technical Memorandum, November 1986. Also paper presented at the Psychonomic Society Meeting, November 1987, with the title: "An empirical evaluation of robust regression applied to reaction-time data."

[7] Turock, D. L. Transformation of visual memory revealed by latency of location-specific matching. Ph.D. Dissertation, Rutgers University, April 1988. (In preparation.)

END
DATE
FILMED
DTIC
JULY 88